XI. *A Classification of Mollusca, based on the "Principle of Cephalization."* By Edward S. Morse.

With a Plate.

[Communicated June 19, 1865.]

After becoming acquainted with the perfect unity of plan in the Radiata and the connected series of homologies, running through the whole branch, (as demonstrated by Prof. Agassiz in his private lectures) my interest was excited, to discover, if possible, a like symmetry of development in the Mollusca. Finding the universality of vertebration among the Vertebrata, of articulation among the Articulata, and similarly of radiation among the Radiata, I could not but believe that in the Mollusca some plan lay hidden, which, when unfolded, would as definitely convey their type, and unite them all, as in the other branches. It is not enough to call them soft bodied animals; for in considering their shell as a part of their organization, we have among them many of the hardest animals known, and we also have an equal number of soft bodied animals in the other branches. Their bilaterality, as expressing anything definite, is an equally unsatisfactory character. Prof. Huxley has given an archetype, or common plan of the Mollusca, as he conceives it, with many truthful homologies, in the article "Mollusca," English Cyclopedia, Vol. III., p. 855. In his figure of the archetype however, which is bilaterally symmetrical, we have details of structure only.

Prof. Agassiz in his "Methods of Study in Natural History" also suggests his idea of the plan, or structure, when he says, p. 34, "Right and left, have the preponderance over the other diameters of the body," and says furthermore, that collectors unconsciously recognize this in the arrangement of their collections. "They instinctively give them the position best calculated to display their distinctive characteristics, and to accomplish this they necessarily place them in such a manner as to show their sides." This can refer only to the Lamellibranchs, and their shells are displayed on the sides, because they naturally fall in that position. This lateral preponderance of structure only obtains among the Lamellibranchs. All Brachiopods

are displayed from the dorsal or ventral valve. Also the Gasteropods, particularly the flat forms like Patella, Chiton, etc. and the Nudibranchs as well, while in the figures of the naked Cephalopods we most usually have a dorsal view.

Though Prof. Agassiz speaks of radiation as characterizing the Radiates, and similarly of articulation and vertebration as characterizing the Articulates and Vertebrates, yet Mollusks are spoken of as first introducing the character of bilaterality, or division of parts along a longitudinal axis, that prevails throughout the Animal Kingdom, with the exception of the Radiates. This then can be no restricted definition for the Mollusca, since it pervades the two higher branches ; and who will deny the evidence of bilaterality among the Radiates, the higher Echinoderms for instance, as Clypeastroids and Spatangoids, where we have as good a definition of a longitudinal axis, as we obtain in many Mollusks. Even among the Polyps, as in the Actinaria, the antero-posterior axis is clearly expressed in the undue prominence of the primary radii.

Prof. Dana has been the first to publicly announce the plan of Mollusca, when he says, "The structure essentially a soft, fleshy bag, containing the stomach and viscera, without a radiate structure, and without articulations."*

As far back as 1855 he has presented this thought in his lectures at Yale College.

In the year 1862 Mr. Alpheus Hyatt had independently worked out a similar result, and has already in MSS. notes, the necessary data demonstrating the same.†

Mr. Hyatt also proposes the name Saccata as more fully and truthfully expressing the type, than the unmeaning word Mollusca. This name not only expresses the Plan, but is equivalent to the titles Vertebrata, Articulata, and Radiata, and is in no way a qualitative appellation.

*Dana's Manual of Geology, p. 148.

†Mr. Hyatt has relinquished all ideas of publishing on this subject, since becoming aware that I was to do the same. During the preparation of these pages, I enjoyed his companionship, and many of the points herein stated, were fully and freely discussed between us, and to him I am indebted not only for the privilege of announcing his proposed name, Saccata, but for the suggestion of certain points to be hereinafter mentioned.

Objecting as all must to the introduction of a new name, still one so appropriate as that proposed by Mr. Hyatt, in lieu of one that has no relation to the Branch, except its traditional use, is certainly worthy of consideration, as it so clearly indicates what is believed to be the fundamental idea in the Branch, that of the Sac.

It might be said, in one sense of the word, that all animals are bags, or sacs, in various degrees of development. And if we mistake not, Prof. Pierce of Harvard University has expressed this idea, modified by saying that one is a radiate sac, another a simple sac, another an articulate sac, and finally a vertebrate sac, or a sac having two compartments. Viewing the Radiates as degradational, in relation to the higher animals, or partaking a plant-like character, we may justly be allowed to remark, that the Mollusks, as a type, present the sac feature most completely, for nowhere (with few exceptions, e. g. Cirripeds), do we find the various organs so essentially concealed, or possessing the power of retraction within a sac, as in the Mollusca. And that this is the leading feature in Mollusca might properly be inferred from the following; that in the four prominent branches of the Animal Kingdom, we have sketched out, in the incipient stages of the embryo, or at least, in its first indications of permanent characters, its typical features.

Thus, in the vertebrate ovum, after segmentation, we have the area pellucida, and primitive trace as indicating the future region, and direction of the vertebrate column. Among the Articulates, we have the transverse division of the embryo: and certainly the most prominent feature in the Molluscan embryo is the sac or mantle; as in the Gasteropods, where we not only have in the embryo a mantle developed, but a distinct nautoloid shell, from which the little animal thrusts himself. In Cephalopods also, as Köl-liker has shown in the development of Sepia officinalis, the mantle, or sac, is the first figure traced on the germ mass.

In my search after homologies between the different groups in this Branch, I always met with difficulty in the relations of the classes;—and though many of the views to be presented, I had long ago worked out, and had consid-

ered, and tested them, by personal examinations of the animals, it was not till I comprehended the importance of the sac character, and understood the "Principles of Cephalization" first enunciated by Prof. Dana, that I was enabled to clear up previous doubts, discover new relations, and, as I believe, rightly interpret the relations of the classes.

"As the principle of Cephalization is involved in the very foundation of the diverse forms that make up the animal kingdom, we may look to it for authoritative guidance, with reference to the system that prevails among these forms."*

In the following considerations, all preconceived ideas regarding the relative positions of the dorso-ventral, and antero-posterior diameters of the animal must be laid aside, and the essential structure of the animal if rightly understood, must be our guide. The gradual morphological changes of the contents of the sac, and all other relations, are based on the principle of Cephalization. In the plate presented (Series I) I have given a typical figure of the six prominent groups of the Saccata; namely, Polyzoa, Brachiopoda, Tunicata, Lamellibranchiata, Gasteropoda, and Cephalopoda.

For obvious reasons, only the intestine, head, and pedal ganglia within the sac are represented. These six figures are placed in their normal position, anterior pole downward, the dorsal region is turned to the left. Commencing with the Polyzoa (Series I, P) we have the sac closed, while the mouth and anus terminate close together at the posterior pole of the sac; the mouth occupying the extreme posterior position, and by a dorsal bend of the intestine upon itself, terminating dorsally. The nerve mass is found between the oral and anal openings. In this class the mouth and anus have the power of protrusion from the sac. In the three lower orders, Cyclostomata, Ctenostomata, and Cheilostomata, the polyzoon, when completely evaginated, presents no fold or inversion of the sac, while in the higher group Phylactolæmata, there is a partial and permanent inversion of the sac under like conditions.

* "Classification of animals based on the principle of Cephalization." Dana, Amer. Jour. Sci., Second Series, Vol. XXXVI., p. 321.

This latter group, combining the permanent inversion of the sac-walls with the lophophoric arms, is the first approach to the Brachiopoda. No organ corresponding to a heart has yet been discovered. In the Brachiopoda (Series I, B) we have a permanent invagination of the sac, and the mouth, as in Terebratula, already occupies a position some distance from the posterior edges of the overlapping shells, and the brachial coils permanently occupy the space thus made.*

We have in this group a dorsal flexure of the intestine, and a tendency to terminate as in the Polyzoa. In Lingula it terminates posteriorly and at one side. By the permanent inversion of the sac, the mouth makes a great advance toward the anterior pole. In Terebratula, Waldheimia, and allied genera, where the sac is very short and swollen, and the brachial coils very large, the viscera are crushed to the front, and the intestine, which is short and simple, is nearly bent upon itself, though still occupying a median line. In Lingula, where we have a very long and flat sac, the intestine is long, and has ample room for convolutions, but the anus, instead of terminating in a line with the mouth, is thrown to one side, in consequence of this excessive flatness of the sac. The heart will be found on the outer bend of the intestine and actually on the ventral side; the nerve occupying its homological position.

(The manner in which I view the Brachiopoda, if true, will entirely reverse the accepted poles of their structure. What has been considered as dorsal, is here regarded as ventral, and what has been considered as anterior, is here regarded as posterior. Further remarks on this will be made hereafter).

Thus far the balance of structure has been thrown to the posterior pole of the sac, and though we see a cephalization, or concentration of the muscular system and viscera, toward the anterior pole in Brachiopoda, yet that pole being essentially closed, we have no function manifested at that end, except the degradational one of adhesion. In

* "Terebratulina caput-serpentes, and Crania anomala, projected their cirri beyond the margin of the open valves, and moved them as the Polyzoa move their oral tentacles, but in no instance were the arms extended." Woodward's Treatise, p. 466.

the Tunicata (Series I, T) we have, through continued cephalization, the mouth thrown to the bottom of the sac, or nearer the anterior end, and now the anus terminates behind the mouth, and posteriorly.

The heart has also followed the intestine in its rotation and becomes anterior, and partially dorsal. The nerve mass is still posterior, and occupies a position between the two openings as in Polyzoa.

We have commencing in this group, the Tunicata, that erratic bending of intestine, and varied position in its anal termination, that is witnessed higher up in the scale, and though apparently governed by no law, we can yet trace the progressive movements toward a normal condition, by comparing Appendicularia, one of the lowest forms of the Tunicates, and representing the larval condition of their class. In this form the intestine has a ventral flexure, and terminates on the ventral side. In Pyrosoma it makes an abrupt bend toward the anterior dorsal region, and terminates anteriorly. In Salpa it terminates dorsally, on a line with the mouth, though still anteriorly. In Botryllus it creeps up, and terminates nearer the posterior pole of sac, though still dorsally. We have in this genus, and other compound Ascidians, the excurrent orifices of several individuals coalescing, forming a common cloaca for a community. The dorsal flexure is distinctly seen in Clavellina borealis. In these three classes; namely, Polyzoa, Brachiopoda, and Tunicata, the sac is essentially closed at the anterior end, and consequently the mouth opens toward the posterior end, and with few exceptions all are attached by the anterior end.

This makes a natural division, corresponding to the Molluscoidea of Milne-Edwards, the Anthoid Mollusks of Dana, and a portion of the neural division of Huxley. In the Lamellibranchiata (Series I, L) we have the sac opening anteriorly, and the mouth permanently occupying the anterior region, though in the lower forms pointing posteriorly, and in all cases the tentacular lobes pointing in that direction, and the mouth bent downward (ventrally), and partially obstructed by the anterior adductor, or by the undivided mantle. The gradual enlargement of the anterior opening is clearly seen, where in the Gastrochœ-

nidæ, we have first a minute orifice, for the passage of an immature foot, or metapodium; this opening gradually enlarging in different genera, until in the Unionidæ we have the sac almost completely separated, except dorsally. It will be noticed that the anterior opening is also ventral, or nearly so in the lower forms. In Gasteropoda (Series I, G) the posterior end of the sac becomes essentially closed, and the ambient fluid now finds access to the gills through the anterior (though partially ventral) portion of sac, while with Cephalopoda (Series I, C) the opening is all anterior. Thus far we have traced the gradual cephalization of the contents of the sac, and of the sac itself. The dotted lines X X, running through the oral opening of each figure in Series I of Plate, show the gradual advance of this opening from the lower to the higher classes. In the lowest class all the display of structure, with the oral and anal openings, lies at the posterior pole of sac. In this highest class, all this display of structure lies at the anterior pole. Advancing from the Polyzoa, by the gradual advance of the mouth, the posterior pole becomes less prominent. Even when the sac opens anteriorly as in the Lamellibranchiata, the posterior end of sac remains open, and the mouth, partially inclined that way, receives its food from that end; the food being conducted to the mouth by ciliary motion as in the three lower classes. The nature of their food is also identical, being of an infusorial character, and as such it is obvious that masticating organs, or biting plates, such as we find in the two higher classes, are not needed.

So long also as the posterior end of the sac remains open, the anus terminates at that end; when this opening becomes closed, as in the higher classes, the anus seeks an outlet through the anterior opening, and the mouth, that before received its food from the posterior end of the sac, and by ciliary motion, now distinctly points the opposite way, and is furnished with the proper organs to procure food, the nature of which requires separation and trituration.

In nearly all the foregoing homologies, and also the position in which I place the Tunicate sac, I am sustained by the writings of eminent naturalists. With the Brachiopoda, however, my views completely reverse the accepted

poles of the body, though, even here, according to "Woodward's Treatise on Mollusca," page 204, Forskahl and Lamarck "compared *Hyalea* with *Terebratula;* but they made the ventral plate of one answer to the dorsal valve of the other, and the anterior cephalic orifice of the pteropodous shell correspond to the *posterior*, byssal foramen of the bivalve!" And, if the views I advance prove correct, they were precisely right. In all my previous attempts to homologize the different classes, I had always met with an obstacle in the apparently aberrant characters of the Brachiopods: never for a moment doubting the truth of the accepted views, that indicated the regions to be called dorsal and ventral, as such, I labored in vain. When I undertook to interpret the relation of these classes on the principle of cephalization, I found that these accepted views must be doubted, and it was with amazement that I beheld such unlooked for results: that the so-called anterior pole is really the posterior pole, and that the so-called dorsal region is really the ventral region.

It has not been without patient consideration that I now advance these views, knowing that by many they will be received with opposition; nevertheless, the more I try to make them comformable with already received relations, the more I am convinced that such relations are wrong; and it is only in believing that continued research will but confirm these propositions, that I now dare to offer them.

According to the views here advanced, the Brachiopods are attached by a prolongation from the *dorsal* area, as in the lower Polyzoa, where they lie on the back. That in their natural position in life, this valve is really uppermost. That the process of attachment also proceeds from the anterior pole of the body, as in all the members of the Branch even to Gasteropods, with the exception of those attached by one valve, (e. g. Ostreans, Clavagella,) whether it be by a byssus, confined in cells of their own making, or buried in the mud, it is the anterior end which is fixed. In several lower forms, like Tridacna and Anomia, the point of attachment springs from the dorsal area, as in the two lowest classes. In regard to the posterior position of the mouth in Polyzoa and Brachiopoda, we have similar anal-

ogies among the Articulata; Cirripedia, for example, where we have animals becoming attached head downward, and all the oral parts, as in the pedunculated forms, tending towards the posterior pole of the body; or in Limulus, where we have such a decephalization as it were, the mouth occupies nearly a central position in the ventral region.

Again, considering the intestine as a simple tube, opening at each end, with the weight of structure evenly divided between the two openings, is it any more incredulous, that the oral opening should be posterior, than that the anal opening should be anterior, as in the Gasteropods?

In Polyzoa, the oral and anal openings occupy a similar position in all the forms. In Brachiopods, while the mouth remains in nearly a constant position, the anus terminates either in a median line, or by a lateral deflection of intestine to one side. In Tunicata, while the mouth occupies a permanent position at the front of the sac, the anus terminates at various portions of the sac, generally in a median line, though there is usually a lateral deflection of the intestine.

In Lamellibranchiata, the mouth and anus terminate in a median line, with few exceptions, (e. g. Pecten) though the intestine convolutes in various ways. In Gasteropods we have again lateral deflection of intestine, and though in many genera the anus terminates in a median line, yet in the bulk of the Gasteropods it terminates at one side or the other. In the Dibranchiate Cephalopods we have again the termination of the intestine in a median line.

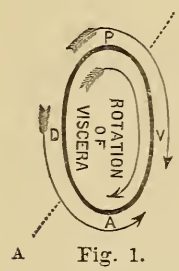


Fig. 1.

The diagram here given (Fig. 1) represents an ideal longitudinal section of the sac, similar to those of Series I. The arrow within the sac, shows the direction of rotation of the bent intestine, carrying with it the heart, (see Plate, Series I.) which in Brachiopoda we find on the ventral region; in Tunicata on the anterior dorsal region; in Lamellibranchiata on the dorsal region; in Gasteropoda on the dorsal region and also further back; and in the Cephalopods at the posterior portion of sac. The different positions of the sac openings (represented in fig.

1 by arrow O) follow the same direction, that is, from posterior to anterior, ventrally. Thus in Tunicata the two openings are posterior and posterior dorsal; the posterior dorsal, being the anal or excurrent orifice; this is always the shortest in Tunicata. In Lamellibranchiata the anal tube moves nearer the branchial tube; in the lower forms their outer covering coalescing and of equal length, while, higher up, the tubes becoming entirely separate, and in some of extreme length, the anal tube being the longest. In Pisidium and other forms the branchial tube disappears, and water is received through a ventral opening; while the anal tube yet remains, occupying a posterior position on a line with the antero-posterior axis, in the same position the branchial tube occupied in the Tunicata: and, finally, both tubes become nearly obsolete, and the mantle is cleft all round, except dorsally. Thus the progress of sac opening follows in the same line of rotation with the intestine. The progressive regions of attachment move in an opposite direction (Fig. 1, arrow A). Commencing with the Polyzoa as the lowest class, we have, as in the Cheilostomata, the dorsal portion large and spreading, this being the fixed portion; the anal opening being turned toward this region, as in the Brachiopoda and Tunicata. (The movable part of the ventral surface, which is uppermost, being represented by the little lid). This mode of attachment is the lowest feature; namely, attached along the entire dorsal region.

As we ascend to the higher forms of the class, we have a freeing of the posterior portion of sac, and the viscera permanently occupies this freed portion. In the Brachiopoda we have the sac free, held only by the peduncle; the means of attachment springing anterior, and from the dorsal valve, as in the partially freed Polyzoon. (Crania and Descina are attached as in Lepralia).

In Lingula, where we have the lengthened and flattened sac, the animal stands vertical in the sand. In Terebratula and allied genera, the dorsal valve already assumes preponderance over the ventral valve, and now obtains its normal position uppermost.

All the Tunicates with few exceptions are attached, and by their anterior end.

In the compound Ascidians like Botryllus, where we have a community of individuals clustering round a common centre, their dorsal as well as anterior regions are attached, or, in other words, the ventral and posterior regions are free only.

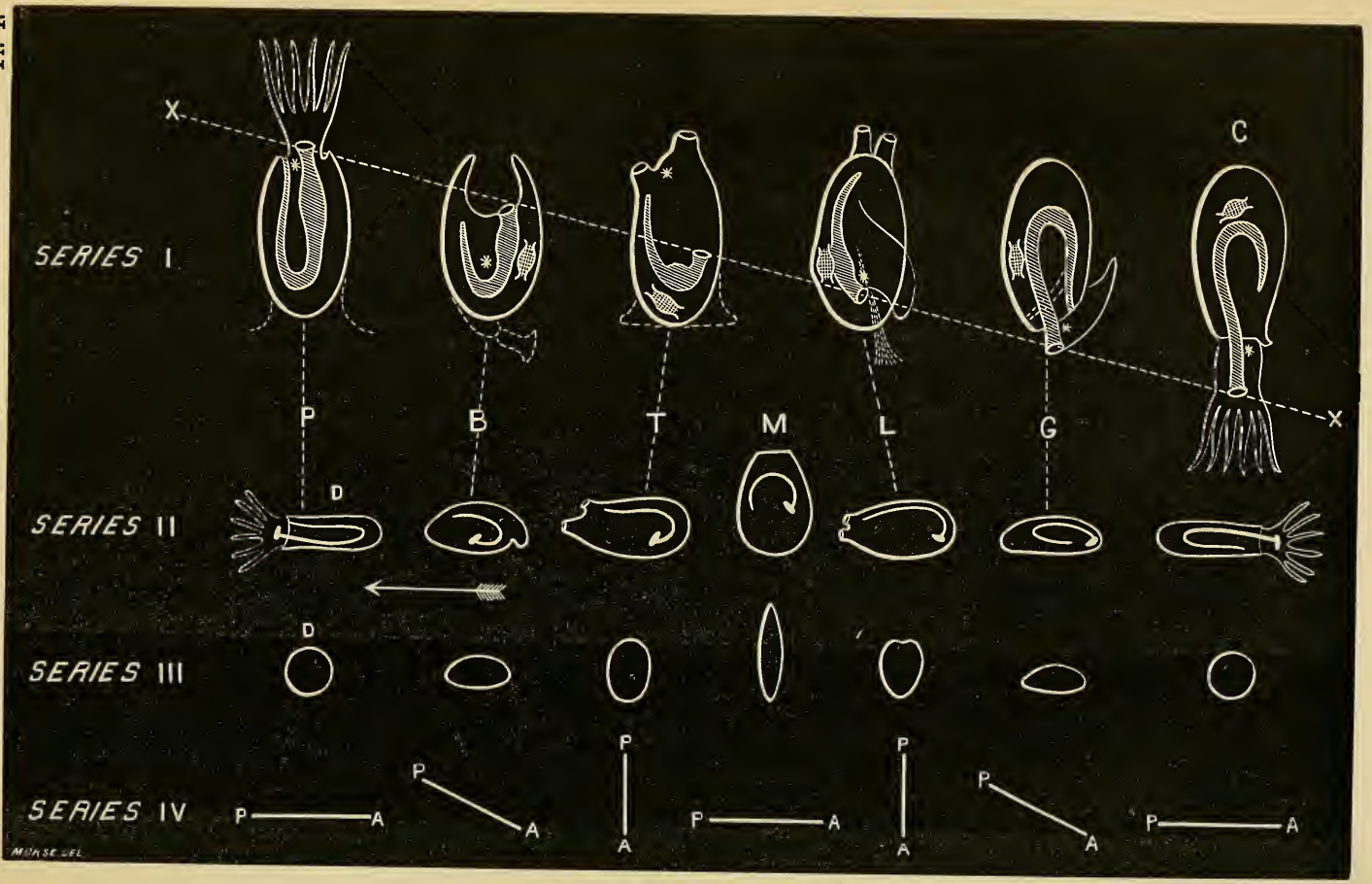
Among the Lamellibranchiata nearly all the lower forms, and many of the higher forms are fixed or stationary; and whether moored by a byssus, buried immovable in the mud, or imprisoned in cells of their own making, it is the anterior end which is fixed. This obtains, with important exceptions.

The Monomyarians combine in their structure both high and low characters. In their open mantle, and certain other features, they rank high. In their fixed position, the attachment generally springing from the dorsal region, they rank low. For these reasons, I have placed them in the centre (see Plate, Series II, M) not indicating by this their equal value with the other groups, for I doubt if their separation from the Dimyarians is valid, since the large adductor, composed of two elements, would indicate the presence of both anterior and posterior adductors, combined in consequence of the excessive shortness of their antero-posterior diameter. The Monomyarians present singular features of analogy with the Brachiopoda. Thus they are generally inequivalve. The viscera are compacted toward the dorsal region, and, when attached, they are generally by a process from the dorsal portion, (e. g. Anomia) the lowest feature of attachment. In all these instances, particularly with Anomia, the analogy is very striking; it is analogy only, and nothing more, for in their whole structure, and in the relative proportion of their diameters, they present just the opposite extreme. While we have in Brachiopoda the growth laterally, that is, spreading on the sides and depressed dorsally, and the valves, dorsal and ventral, in the Monomyarians we have the other extreme; the valves are right and left, and the display is on the side, the growth extending ventrally as it were. So narrow are they that in certain forms, Placuna for example, it is almost impossible to conceive the presence of soft parts between the valves. We compare the relative diameters between the Brachiopods and Monomyarians, to show how unlike they are in this respect.

ERRATA.

Page 175, line 12 from bottom, for anterior pole *read* posterior pole.

Page 180, lines 12—13 from top, for anterior end *read* posterior end.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Diameter.	Brachiopods.	Monomyarians.
Antero-posterior.	Medium.	Small.
Dorso-ventral.	Small.	Very large.
Transverse.	Large.	Very small.

For reason of their excessive narrowness, the greater number of Monomyarians lie on the right or left valve, and as their peculiar form precludes the possibility of locomotion by the usual organ, the foot, they either remain fixed, or swim freely about in the water, by violently closing their valves, as in Lima and Pecten.

Among the Unionidæ, the highest family in the Lamellibranchiata, the animal assumes nearly a horizontal position in crawling, though the anterior end is always the lowest, and generally buried in the mud. Its embryos, like Monomyarians in shape, are attached to the ovisac by the dorsal margin, which is straight, as in Pecten. (Lea's paper on Embryonic forms of Unionidæ, Journ. Acad. Nat. Sci., 2d Series, Vol. IV., plate 5).

By their violent shutting of the valves, while in embryo, they may, after birth, swim, even as Pecten swims; at all events they are said to become attached by a byssal thread while young. Among the Gasteropods we have a few genera attached, or fixed, as in Magilus, Siliquaria, Vermetus, Spiroglyphus, Nerinæa, and Petaloconchus. These are now attached posterior end downward. In Calyptræa they are in a fixed position, secreting a ventral valve, upon which they rest. (It would be interesting to know for a certainty which part first becomes attached in Vermetus and allied forms; their first point of attachment must take place at the mouth of the tube or aperture, which is really anterior and ventral). The Cephalopods are free.

Thus we have the various regions of attachment, changing and following in the direction indicated by the arrow A, in Fig. 1.

1st, Polyzoa: dorsal attachment.

2d, Brachiopoda: dorsal and anterior attachment.

3d, Tunicata: anterior.

4th, Lamellibranchiata: anterior and ventral attachment.

5th, Gasteropods: ventral and posterior attachment.

While we have thus seen that the area of attachment first springs from the *dorsal* region, and gradually changes as we ascend in structure toward the anterior end, so we find the principal organ of locomotion, i. e. the foot, is first developed from the *ventral* region, and in like manner tending toward the anterior end, as we ascend in the scale, until, in Cephalopoda, the specialized divisions of the foot surround the head, and point directly forward.

Having personally communicated the substance of this paper to Professor James D. Dana, he has, in a letter to me, indicated certain gradient relations among the Lamellibranchs, Gasteropods, and Cephalopods, as manifested in the special characteristics of the head, or anterior part of the body, so clearly illustrating the principle of Cephalization that I now take the liberty of presenting them. In the Lamellibranchs the foot is a simple muscular organ developed from the ventral surface and protruding anteriorly. It is simply an organ of locomotion, in the lower forms not even performing this function. The oral opening is a simple slit, without the power of seizing or triturating its food.

In the Gasteropods the foot is more specialized, and as an organ of locomotion far superior to that of the Lamellibranchiates, having oftentimes three well characterized regions, called by Huxley, the pro- meso- and metapodium, these regions oftentimes supporting certain processes, e. g. cirri, opercula. The foot not only performs locomotion but in many cases has the power of seizing and retaining its prey (e. g. Natica). The mouth has an apparatus for biting and triturating its food, being furnished with an upper jaw, or buccal plate, and a tongue, armed with silicious particles. In the Cephalopoda the foot is so far differentiated as to be separated into prehensile arms furnished with rows of suckers, or hooks. These arms surround the head, and are thrown directly forward. They are capable not only of locomotion, but of seizing their prey, and performing also movements of aggressive action. In the higher forms of Cephalopods, the function of locomotion is delegated to other organs, while the arms subserve the uses of the head alone, and the mouth, furnished with two powerful mandibles opposed vertically, forcibly

reminds us of a parrot's beak, or that of certain other vertebrates. Thus we have cephalic power manifested in the mechanical action of the foot.

1st, Lamellibranchs—Locomotion.

2d, Gasteropods—Locomotion, Prehension.

3d. Cephalopods—Locomotion, Prehension, and Aggression.

According to the principle of Cephalization, cephalic power is manifested either as a mechanical, sensorial, or psychical force. Thus the Cephalopods possess in the greatest measure, all three; while Gasteropods, not indicating, to any great extent, aggressive action, may be said to manifest but little psychical power; and the Lamellibranchiates manifest essentially only mechanical action.

We have based the preceding considerations on the common structure of each class, and for comparison have given an archetype, as it were, of each class (Series I). In continuing these archetypal figures, as illustrating the relative diameters and mean forms for each class (Series II and III), and also the mean, or average position in nature of the antero-posterior axis (Series IV), we obtain singular features of polarity,* which I will now proceed to indicate; premising, however, that what follows is offered with reluctance, as I have not at present the opportunity to verify the statements as I would wish. In Series II the average lateral form of each class is given. In Series III a transverse section is given of the same figures in Series II. In Series II the arrow A indicates the direction of anterior pole, and D indicates the dorsal region in Series II and III. In Series IV a line for each class is given, representing the average position of their antero-posterior axis in nature (A, anterior pole, P, posterior pole). The central figures in Series II, III, and IV represent corresponding views of the Monomyarians. In the Polyzoa, (Series II, P) the sac is long and cylindrical, the mouth and anus terminate at the posterior pole, and the tentacles surround the mouth only; the anus terminating outside the lophophore. Witness in the highest order of Cephalopods, the Dibranchiates, the sac as in Loligo (Series II, C), long and cylindrical, and in all cases mouth and

*We use this word in its most general sense.

anus opening anteriorly; the arms surrounding the mouth only. Two rough diagrams, alike in form, but reversed in one case, would represent each class as we have it here.

In Brachiopoda (Series II, B) we have the sac widening laterally, and correspondingly depressed dorsally; mouth and anus opening posteriorly. In Gasteropoda (Series II, G) we have the same features, except that the parts are reversed again. In Tunicata (Series II, T) the sac is lengthened and swollen. Lamellibranchiata (Series II, L) the same. The relative diameters of the Monomyarians are unlike those of any other class, as before pointed out.

It is confidently believed that when these relations, or polarities, between the ascending, and descending, or, as Professor Dana terms them, the Holozoic and Phytozoic classes, have been farther studied, new and interesting features will be revealed. Thus, the resemblances between the Tunicates and Lamellibranchiates are too obvious to indicate.

Among the Brachiopods and Gasteropods, beside what has been pointed out, we have unlooked for similarities, as for instance Descina and Calyptræa, or Terebratula and Hyalæa. Among the Polyzoa and Cephalopoda, though no polarities are brought to mind, except those given above, yet we cannot help remarking how strong the resemblance is between the Polyzoa and Protozoa, through Vorticella: and if Vorticella belongs to Polyzoa, as Professor Agassiz appears inclined to believe, a few steps more bring us to the Ammonitic forms of the Rhizopods. This is speculative (though suggestive), as it is now considered by many that the Protozoa forms a fifth Sub-Kingdom.

In considering a transverse section of the sacs, as shown in Series III, we obtain a like order of polarity. Thus the highest orders in Polyzoa and Cephalopoda present a circular section. Brachiopoda and Gasteropoda are transversely oval; Tunicates and Lamellibranchiates are longitudinally oval, or in lower forms circular; while the Monomyarians have the dorso-ventral diameter in excess, and the transverse diameter reduced to the minimum.

In considering the position, or angle of the antero-posterior axis of each class in nature, we obtain similar results (Series IV).

Polyzoa and Cephalopoda, we place in a horizontal position, taking a swimming Dibranchiate for comparison: this may be premature however.

Brachiopods and Gasteropods with posterior pole slightly elevated, as in Cyrtia and allied forms of Brachiopods, and any coiled Gasteropod for example. Tunicates and Lamellibranchiates with the axis vertical, the anterior pole being below, and the Monomyarian horizontal again. It must be remembered that the above considerations are taken in their most general sense, representing only the mean for each group, many of them perhaps erroneous. They are given rather for the purpose of indicating a future path of inquiry, which the writer considers fruitful and intends to follow, than as points in any way settled.

In ascertaining the mean position of the antero-posterior axis for the whole branch of Saccata, (that is, the average) we find that a line at an angle of 45° would represent its position in nature; the lower end being anterior. In the Radiates a line through the mouth to the opposite region of the body would stand vertical. In Articulates the antero-posterior axis would be horizontal. Among the Vertebrates, Fishes would be horizontal, as in Articulates; Reptiles have the head slightly elevated; Birds and Mammals still more elevated; so that a mean line, for these classes might be drawn at an angle of 45,° the cephalic region being uppermost. Man stands vertical. Thus in a diagram we would have the following:

Fig. 2.

In the preceding considerations I have endeavored to show the importance of the sac, as the principal and prominent feature in their plan of structure. All animals, re-

duced to their primary elements, are sacs in one sense of the word, though in one case a radiate sac, in another an articulate sac, etc. Yet nowhere does this character predominate so universally, nor is it expressed so simply as in the Mollusca; the leading idea as it were. It was shown also that, essentially, the heart is on the outer bend of the intestine, or between that and the sac wall, while the principal nerve mass was on the inner bend of the intestine. We would thus state their characters.

SACCATA.

(1) *Animals of a varied form, without a radiate structure and without articulations.*

(2) *Stomach and viscera enclosed by a fleshy sac, which may be closed or open, at either one or both ends.*

(3) *Principal nerve masses, consisting of ganglia, which are adjacent to, or surround the œsophagus.*

(4) *Intestine bending inward, or having an outward flexure.*

(5) *Heart on the outer bend of intestine.*

- SACCATA.
  - HOLOZOIC, OR TYPIC. *Mouth opens anteriorly.*
    - Sac open at anterior end.
      - CEPHALOPODA.
      - GASTEROPODA.
    - Sac opens at both ends.
      - LAMELLIBRANCHIATA.
  - PHYTOZOIC, OR HEMITYPIC. *Mouth opens posteriorly.*
    - Sac open at posterior end.
      - TUNICATA.
    - Sac closed.
      - BRACHIOPODA.
      - POLYZOA.

We must now consider the relations of the Saccata to the other branches of the Animal Kingdom. In the paper of Professor Dana's, above referred to, he has used the terms alphatypic, betatypic, and gammatypic, as a numbering of the grades of types, whether of branches, classes, or orders; also, below gammatypic, we have degradational.

The Radiates are regarded as degradational, and below this, hemiphytoid, also, the terms used above, namely, Holozoic, or true animal forms, and Phytozoic, or plant-like forms.

Applying these terms to the classes or groups of Saccata, we have the following:

Holozoic.	Alphatypic,	Cephalopoda.
	Betatypic,	Gasteropoda.
	Gammatypic,	Lamellibranchiata.
Phytozoic.	Degradational,	Tunicata.
		Brachiopoda.
	Hemiphytoid,	Polyzoa.

Prof. Danahas pointed out many interesting parallelisms between the groups of the different branches. Let us now look at the parallelisms between the groups above indicated, and the other branches. Cephalopods approach nearest the Vertebrates through their lowest class, the fishes, and already many interesting analogies have been pointed out between them.

Gasteropods may be likened to Articulates, through their lowest class, the Worms, through certain resemblances many forms bear to the Leeches, Planarians, and Trematodes. Lamellibranchiates may be considered the essential embodiment of the branch to which they belong. Tunicates and Polyzoa may be compared to Radiates.

Or, in considering their freedom or fixedness in life, we have Cephalopods free, as in all Vertebrates; Gasteropods, a few fixed, as in Articulates; Lamellibranchiates, many fixed as in Saccata, with relation to the other Branches. Tunicates, the greater portion fixed, though they do not compare so well with the Radiates in this respect, but Brachiopods and Polyzoa fixed as in the lowest class of Radiates, the Polyps.

We would thus have

Alphatypic,	*Cephalopds,*	*Vertebrates,*	Fishes.
Gammatypic,	*Gasteropods,*	*Articulates,*	Worms.
Betatypic,	*Lamellibranchiates,*	*Saccates.*	
Degradational,	*Tunicates, Brachiopods,*	*Radiates.*	
Hemiphytoid,	*Polyzoa,*	*Radiates,*	Polyps.

Explanation of Plate IV.

Series I. Represents a typical figure of each principal group in Mollusca—viz., P, Polyzoa; B, Brachiopoda; T, Tunicata; L, Lamellibranchiata; G, Gasteropoda; and C, Cephalopoda—(M, indicating Monomyaria, of the second series). These figures are represented anterior end downward, the dorsal region being turned to the left. The tube within each cut, represents the intestine, the larger end of which is the mouth, and the smaller end the anus. The harp-shaped figure represents the heart, and the star represents the pedal ganglion.

Series II. Represents similar views, with less detail. The dorsal region in this series is uppermost, and the anterior end, is turned to the left, as indicated by arrow A. The curved line indicates the intestine, the large end being the mouth.

Series III. Represents transverse sections of corresponding figures in Series II.

Series IV. Represents the mean position in nature, of the antero-posterior axes of the figures represented above, A, Anterior pole, P, Posterior pole. The vertical rows of figures are identical.

Note. Since lines 7—12, page 164, were printed I have had an opportunity of quoting the remarks made by Professor Peirce as reported in the Proc. Amer. Acad. Arts and Sci., Vol. III, p. 8.

"Professor Peirce also presented a communication upon the form assumed by an elastic sac containing a fluid.

The positions of unstable equilibrium he found to divide themselves into four special forms, the annular, cylindrical, that of a cylinder with a bilateral character, and the double or multiple cylinder. The ultimate form of the first case is a sphere.

He also alluded to the interest of this fact to those who were not themselves mathematicians. For the primitive forms which Professor Agassiz had found to be the four types of the animal kingdom were the same, the Radiata being represented by the sphere, the Mollusca by the cylinder, the Articulata by the bilateral, and the Vertebrata by the double cylinder. Now, as all animal forms begin as elastic sacs, containing fluids, these forms seem the necessary ones for the condition of equilibrium."

It was Mr. Hyatt who defined the animal forms in the terms used on page 164. E. S. M.